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Socio-macroeconomic impacts of implementing different post-Brexit UK energy reduction targets to 2030

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ABSTRACT

For the period since 2011, the UK has been bound by European Union (EU) legislation regarding energy reduction targets to 2020. As of 2019, the UK had reduced its final energy use by 18% against a baseline projection to 2020, on track to meet its target of 18%. Whilst the rest of the EU-27 now set their own energy reduction targets to 2030, upon leaving the EU via Brexit, the UK is now free to choose its own energy targets. But what should the energy target be for 2030, and what are the socio-macroeconomic impacts and policy implications?

To address this, we use two econometric energy-economy models to assess three different levels of energy reduction target, with 27%, 33% and 40% reduction in 2030 versus the baseline model projections. We find the strictest (40%) energy reduction target could deliver the largest economic and employment benefits. However, careful attention to policies are required, to ensure improvements to overall economy-wide energy efficiency whilst minimising rebound. Demand-side policies of serious scale within an 'avoid-shift-improve' framework are required, including massive building retrofits, significant improvements to industrial energy efficiency, switching to low energy transport modes, and moving away from meat-based diets.

1. Introduction

1.1. UK energy targets in a post-brexit policy landscape

Since 2011, the UK has been bound by European Union (EU) legislation regarding energy reduction targets (European Commission, 2011), as part of a wider EU-based commitment to reduce GHG emissions by 80–95% by 2050 compared to 1990 levels (European Commission, 2011). As presented in the EU's Energy Roadmap 2050, not only a shift to renewables in the energy mix (supply-side), but also an overall efficiency-led reduction in energy use is one of the strategy's main targets. The overall EU energy reduction target under their 20-20-20 framework was to achieve a 20% reduction in EU-27 (now EU-28) final energy use by 2020, relative to the EU-PRIMES baseline projection model forecast made in 2007 (Capros et al., 2008), as shown in Fig. 1. As can be seen in Fig. 1, the EU-27 made reasonable progress (albeit in part due to the financial crisis and subsequent recession), and by 2014 had surpassed the objective (−22%). However, final energy consumption started to grow again and by 2018 it was moving away from the −20% target, reaching a −18% reduction against the projected baseline's 2020 target.

The UK's specific country-level target was to reduce final energy use by 18% versus its 2020 projection from the 2007 baseline projections. By 2019, the UK had achieved a 17.7% reduction versus the 2020 projection, and seemed on course to be very close to meeting its target. Whilst on the surface, that would appear a success story, there are two reasons why the continued decline of energy use will not be as straightforward in the future. First is that the 2007 projection was made just before the 2008 global recession, which stunted energy use and economic growth for the decade afterwards. Second, the UK's decline in energy use has been partly due to offshoring of energy use and the structural change to a service-based economy (Hardt et al., 2018), neither of which can continue for much longer.

For the period beyond 2020, the EU has been developing a 2030

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Climate & Energy Framework, which includes working through several steps to set an EU-28 energy reduction target to 2030. First, the EU updated its Reference scenario in a way that only different levels of energy reduction – even with current policies - are considered for the future (European Commission, 2016a). Second, a range of European Commission (EUCO) 2030 energy reduction targets (E3MLab and IIASA, 2016) were tested, spanning from EUCO+27 (−27% final energy reduction in 2030 versus the (revised) baseline model) to EUCO+40 (−40% final energy reduction in 2030 versus the (revised) baseline model. Third, based on these modelling updates and impact assessments, the EU has set a current overall target for "At least 32.5% improvement in energy efficiency".[1] This is equivalent to the EUCO+33 reduction target assessed, (−33% final energy reduction in 2030 versus the (revised) baseline model projection). At the time of writing, it is possible that these targets will be increased to reflect a more ambitious greenhouse gas emission reduction target for the EU in 2030.[2]

The UK reduction targets were almost equivalent to the same EUCO targets, e.g. EUCO+33 was equivalent to a 33% reduction in UK final energy versus the baseline model projection to 2030. The range of possible energy efficiency targets applied to the UK is shown in Fig. 2. These depict EUCO+27, EUCO+33 and EUCO+40 energy reduction targets, representing improvements in energy efficiency of 27%, 33% and 40% respectively versus baseline projections to 2030 (E3MLab and IIASA, 2016).

Three recent events have changed the UK energy policy landscape UK. The first is the decision to the leave the European Union. Post-Brexit, the UK can set its own energy reduction targets. The second is the adoption in 2019 of the UK's Net Zero carbon emissions target by 2050 as formal legislation (HM Government, 2019). Third is the coronavirus pandemic, and what the post-pandemic economy will look like. In such context, a study of the socio-macroeconomic impacts of possible UK energy reduction targets is highly desirable, and is the focus of this paper.

1.2. Assessing the macroeconomic impacts of the implementation of different UK energy targets to 2030

Given the growing evidence of the energy-economy nexus (Hall and Klitgaard, 2012; Stern, 2012; Foxon, 2017; Sakai et al., 2018), a growing body of Integrated Assessment Models (IAMs) or Energy-Economy-Environment (E3) models has been developed during the last decades. The EUCO scenarios were themselves built using the PRIMES model (E3MLab and IIASA, 2016), and their socioeconomic implications were afterwards evaluated by using GEM-E3 (E3MLab, 2016) – a conventional CGE model - and E3ME (Pollitt, 2016).

The objective of this article is evaluating the potential socio-macroeconomic implications of adopting UK-specific energy reduction targets for 2030. As a future UK energy target is not yet stated, and a wide range of existing EUCO scenarios have been developed by the EU, it is the EUCO scenarios applied to the UK that have been assessed in this paper. By understanding the macroeconomic implications of the EUCO scenarios, this article provides useful information for UK policy-makers, in order to decide how far or close to the EU's scenario targets the should UK be. With this purpose, two different models have been employed: E3ME (Cambridge Econometrics, 2019; Mercure et al., 2019) and MARCO-UK (Sakai et al., 2018). Both are energy-economy-environment (E3) models grounded on a macro-econometric (ME) methodology.

Both models can also be considered as policy-evaluation – or, simply, simulation-models. According to Scrieciu et al. (2013), this approach allows for exploring the propagation of the disturbances into the model of different sets of policies. They also rely on non-equilibrium economics, i.e. non-clearing markets and normally are demand-driven, as opposed to optimisation models, based on optimum equilibrium and supply-led. Moreover, simulation models are predominantly empirically validated and based on observed behaviour. As stated by the authors, simulation models tend to rely more on heterodox economics. Accordingly, both E3ME and MARCO-UK are based on Post-Keynesian-Economics. General descriptions of post-Keynesian economics can be found in King (2015) and Lavoie (2015). The formulation of the models goes back to Keynes' original works, particularly *A Treatise on Probability* (Keynes, 1921) and *The General Theory of Employment, Interest and Money* (Keynes, 1936).

An understanding of fundamental uncertainty is key to interpreting the outputs of the models. If agents do not have 'perfect knowledge' of

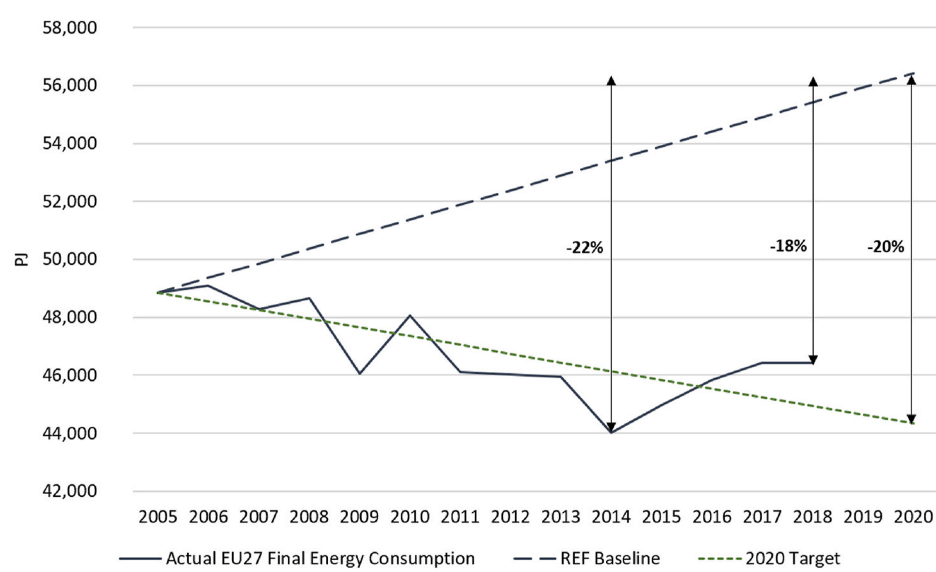


Fig. 1. EU-27– 20% final energy reduction target in 2020 versus 2007 EU PRIMES baseline model projection. Source: Author's own construction from Eurostat data (Eurostat: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en) and baseline model scenario (Capros et al., 2008).

[1] https://ec.europa.eu/clima/policies/strategies/2030_en.

[2] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_1598.

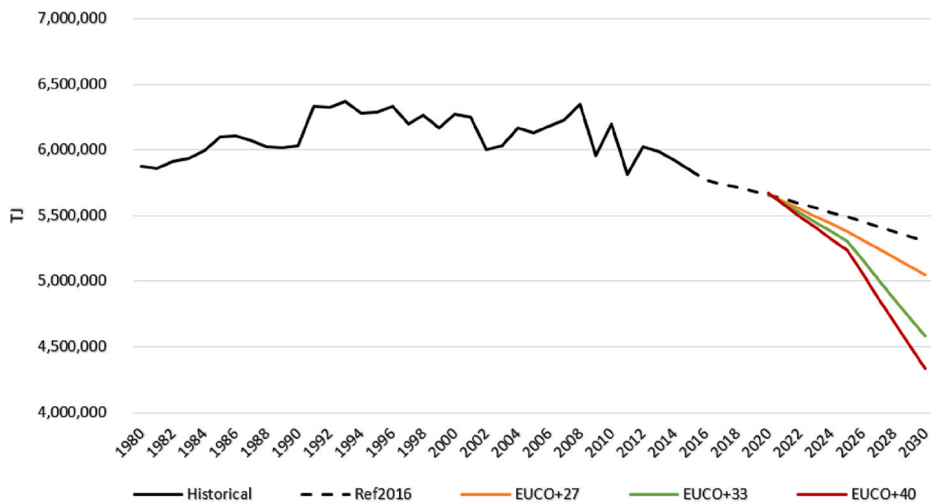


Fig. 2. UK's Total Final Energy Use by EUCO energy reduction targets.

the choices available to them, it is not possible for them to optimise decision making. The assumptions common to Computable General Equilibrium (CGE) models about firms maximising profits and individuals maximising utility become untenable, and an alternative model of behaviour is required.

Both the models used in this paper use econometric techniques to estimate behavioural patterns, drawing on relationships from historical time-series data. This is why they are referred to as macro-econometric models. The econometrics provides a strong empirical basis for the models. While all econometric models are subject to the Lucas Critique (Lucas, 1976) – meaning that these models are based on the past economic structure that might change in the future and thus, potentially changing the model's outcomes - they are no more at risk than other approaches (including CGE) that employ time and/or scenario-invariant parameter (Haldane and Turrell, 2018).

Leaving aside individual parameter values, several system-wide properties of the models emerge from relaxing the assumption about optimising behaviour. Most notably, agents cannot respond predictably to changes in prices and there is no guarantee of market clearing. This means that there may be spare capacity in the economy, for example represented by involuntary unemployment or the 'output gap' that economists try to measure. The level of production is determined primarily by the level of aggregate demand and not supply, with the availability of factors of production only putting upper bounds on the level of potential output.

In such a modelling framework it is possible to assess the effects of fiscal stimulus and austerity. This points towards another key feature of post-Keynesian economics, the importance of money in determining the level of economic activity (Pollitt and Mercure, 2018). When considering policies that will result in high levels of investment (e.g. energy-efficiency mandates), it is crucial to model the financial system in a realistic way, with the size of the money supply responding endogenously to the demand for money (McLeay et al., 2014). Further details about the different modelling approaches is given in Mercure et al. (2019). If the transformations simulated for energy transitions towards sustainability could entail fundamental structural change, dealing with different scenarios is a useful approach to cope with uncertainty. As such, the energy reduction targets are the main inputs to both models, then incorporating thermodynamic constraints and other socioeconomic dials involving the capital investment required, high-skilled labour additions, government expenditures and energy prices. With this background, the impacts of the energy transition in the UK are evaluated in terms of GDP, investment, employment, prices and emissions.

Both MARCO-UK and E3ME are macro-econometric models, meaning that their parameters are estimated on historical time-series data. This modelling approach is increasingly used to explore the implications of different sustainability transitions pathways, providing an alternative to the more standard equilibrium-based approach (see also e. g. (Lutz et al., 2010; Kratena et al., 2013)). Whereas different methodologies are likely to deliver divergent outcomes, different modelling assumptions within the same methodological framework can provide different insights too. Far from considering this as a weakness, by focusing on different areas they contribute to build a more complete frame to understand energy transitions and inform the policy-making process. Therefore, in this paper we compare a highly energy-disaggregated model like E3ME with the results obtained by MARCO-UK, a model able to account with the role of energy efficiency – a key feature of the energy reduction targets - in economic growth. Comparisons between different econometric models is rare, and is therefore one of the novelties of the paper.

The article structure is as follows: section 2 summarises the two models' methodological approaches and outlines the scenario definitions; section 3 describes the main modelling outcomes; section 4 discusses these results and compares them, highlighting how they are determined by the two methodologies; some concluding remarks are made in section 5.

2. Methodology: models and scenarios

2.1. E3ME model

E3ME is an established global macro-econometric model based on post-Keynesian economic theory. It splits the world into 61 regions, with 70 sectors in each region.[3] The model was originally built in the 1990s to assess energy and climate policy at European level but has since been extended to provide global coverage. The UK is one of the 61 regions in the model. The full manual (Cambridge Econometrics, 2019) is available at the model website www.e3me.com. A full list of equations is given in Mercure et al. (2019).

Fig. 3 provides an overview of the different modules in E3ME. The economic structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand

[3] 44 sectors for non-European regions.

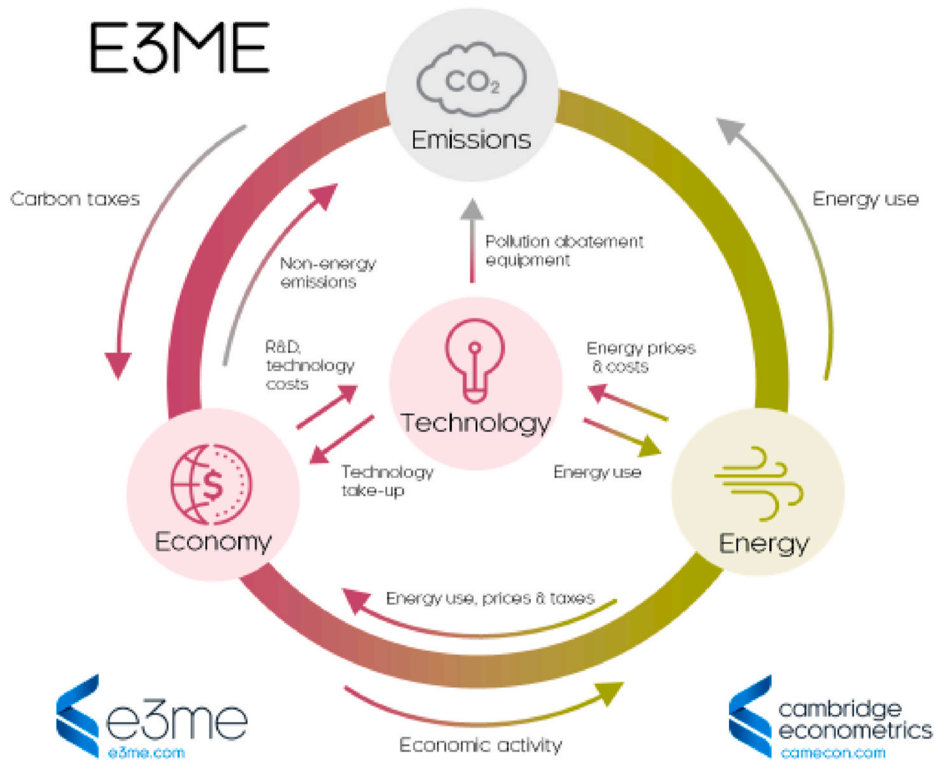


Fig. 3. Schematic E3ME model structure - courtesy of Cambridge Econometrics©.

and materials demand. Each equation set is disaggregated by country and by sector.

Final energy demand in most sectors of the model is determined by a set of econometric equations; the key explanatory variables are levels of production, prices and measures of technological progress. Each sector's total energy demand is then disaggregated by carrier using a similar set of equations. Exogenous changes in energy consumption (e.g. due to regulatory policy) may be added separately. The power generation sector is represented by a model of technology diffusion, which shows potential paths for the adoption of new technologies (Mercure, 2012; Mercure et al., 2014) .[4]

E3ME's historical database covers the period 1970–2018 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA. The historical data are used to estimate the behavioural parameters in the model. The estimation process is a two-stage least squares approach, based on the concepts of cointegration and error-correction methodology, particularly as promoted by (Engle and Granger, 1987) and (Hendry et al., 1984).

E3ME has been used extensively at European level to model energy-efficiency policy, including a detailed analysis in 2015 (Cambridge Econometrics et al., 2015) that drew on previous official analysis of proposed revisions to the Energy Efficiency Directive. The model was also used to assess potential impacts of the recent EU Long-Term Strategy for decarbonisation (European Commission, 2018) and revisions to the 2030 emissions targets to be consistent with net-zero emissions by 2050 (European Commission, 2020).

2.2. MARCO-UK model

UK MAcroeconometric Resource COnsumption (MARCO-UK) is a macro-econometric (ME) model of the UK, covering the historical period 1971–2016, and projections from 2017 up to 2050. MARCO-UK is grounded on Post-Keynesian (PK) economic theory, where agent behaviour is not based on optimisation but is instead determined from econometric equations based on historical data. The economy is conceptualised as a non-equilibrium system assuming sub-optimal markets. Hence, prices and quantities do not adjust to optimal, market-clearing levels. Instead, PK theory considers that prices are set by firms using some form of mark-up pricing, although it is acknowledged that the interplay of supply and demand can impact prices in some markets. In the short run, production adjusts to increased demand through the increase in the utilisation of capacity, while in the long run the total capacity of the economy adjusts to demand through increased levels of investment. However, PK theory recognises that supply-side factors, especially insufficient labour supply, can constrain production in unusual circumstances. MARCO-UK deals with this restriction by rejecting any scenario in which employment outstrips the available labour force. In addition, MARCO-UK allows for testing the impact of thermodynamic efficiency limits on production.

MARCO-UK contains over 70 socio-technical-economic variables, including thermodynamic-based energy variables (primary energy, final energy, and useful exergy; thermodynamic efficiency at primary-to-final and final-to-useful conversion stages). The main novelty of this modelling approach is the inclusion of the end-use energy stage, i.e. useful exergy, as the last energy conversion stage in order to satisfy the demand for energy services. Although typically disregarded in E3 models, the useful exergy stage is where the most energy losses occur. Importantly, these energy variables are fully integrated into the model structure, as opposed to the conventional soft-linking of the energy and economy dimensions. The inclusion of thermodynamic efficiency and useful exergy allows the model to investigate their roles in economic growth. Fig. 4 outlines the overall model construction:

Investments feed the capital stock, improving thermodynamic efficiency and energy services (useful exergy). This, in turn, increases labour and capital productivity which feeds back to further investments boosting economic growth. Simultaneously, energy prices are lowered,

[4] The current version of E3ME also incorporates diffusion models for cars, household heating and the steel sector, but these were not used in this paper.

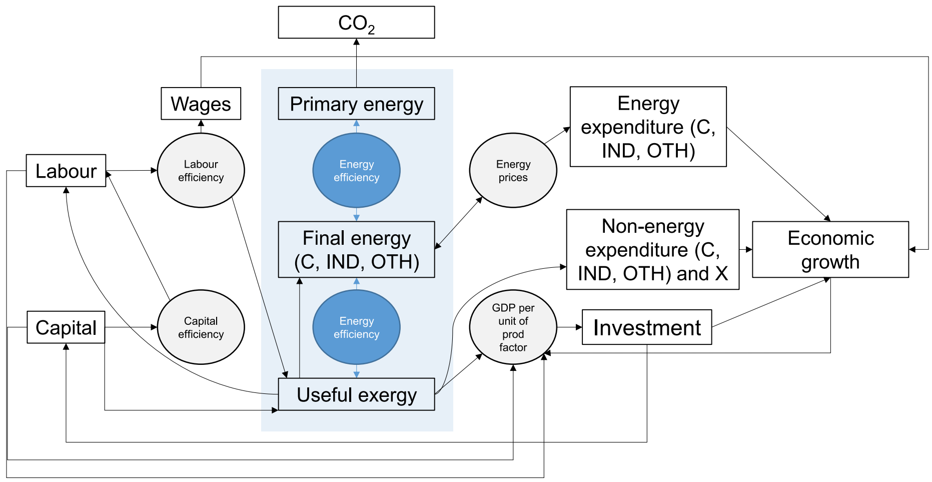


Fig. 4. Schematic MARCO-UK model structure (Sakai et al., 2018).

leading to higher non-energy expenditures, also resulting in higher economic growth both from the producer and the consumer sides. Therefore, rebound effects are included since the lower energy prices could lead to higher energy demand. In MARCO-UK, energy services are demanded, implying a certain final energy and primary energy requirements, according to the final to useful and primary to final energy efficiencies respectively. Finally, energy use results in CO_2 emissions. Nevertheless, as useful exergy grows and capital is more efficient, demand for labour is reduced unless aggregate demand raises sufficiently to offset this effect. These kind of relationships and their implications to the overall results are discussed in section 4.

Like other ME models, MARCO-UK contains two types of equations: identities and behavioural (or stochastic). The first type involves definitional relationships, that must hold true in all time periods. The second type of equations contain parameters estimated econometrically. The present version of the model contains 57 equations: 30 are identities and 27 are stochastic. An extended summary of the MARCO-UK model is presented in Appendix A. For a full description of the model refer to Sakai et al. (2018) – Supplementary Information, where details of each equation and variable are described, including sources for all the annual data used in the model construction.

2.3. Scenarios definition

2.3.1. Summary

For this analysis, simulations have been run until year 2030, since it is the last year for the next EU energy targets, for which the UK has to set its own target now. The E3ME scenarios are taken as a base on which the rest of scenarios are built on. The scenarios summary is collected in Table 1:

For this analysis, both models have produced their own Baseline, endogenous projections. For the sake of improving comparability, the Baseline scenario for both models represent their respective endogenous forecasts without any policy or assumption. In addition, the energy use reduction is an exogenous decrease on final energy demand according with Fig. 2. This is applied to all E3ME and MARCO-UK scenarios except Baseline.

2.3.2. E3ME modelling assumptions

The scenarios are implemented as ceiling caps on the absolute level of energy consumption in the UK. Effectively, a regulatory policy is put in place that forces businesses and households to adopt methods to reduce energy consumption.

E3ME does not make a judgment about the potential thermodynamic (energy) efficiency of different sectors; it is taken by assumption that the energy savings can be made through changes in methods of production, without requiring decreases in the absolute level of production. The inputs to the model are thus an exogenous reduction in energy consumption and the investment that is needed to make this reduction in consumption occur. A final assumption is made about who pays for the investment; in these scenarios it is assumed that households offset other consumption to invest in energy efficiency, businesses increase product prices and government increases the standard rate of income tax.

2.3.3. MARCO-UK modelling assumptions

The MARCO-UK scenarios incorporate two key additional features. First are the constraints placed on the final-to-useful thermodynamic efficiency (EXEFF_FU): we set this at an exogenous value in MARCO27a,

Table 1
Summary of E3ME and MARCO-UK scenarios assumptions.

	Scenario	Energy features	Socioeconomic features & Thermodynamic Efficiency constraints			
	Baseline (BL)	No policies scenario				
E3ME	**E3ME27**	EUCO27 energy reduction.	–			
	E3ME33	EUCO33 energy reduction.				
	E3ME40	EUCO40 energy reduction.				
MARCO-UK	**MARCO27a**	EUCO27 energy reduction.	Thermodynamic efficiency constrained at 10% higher than Baseline in 2030			
	MARCO33a	EUCO33 energy reduction.	Thermodynamic efficiency constrained at 15% higher than Baseline in 2030			
	MARCO40a	EUCO40 energy reduction.	Thermodynamic efficiency constrained at 20% higher than Baseline in 2030			
			Investment[a]	**Skills**[b]	**Energy prices**	**Gov. Expenditures**
	MARCO27b	EUCO27 energy reduction.	+10%	+1%	Equal to Baseline	19% GDP
	MARCO33b	EUCO33 energy reduction.	+15%	+1.5%		
	MARCO40b	EUCO40 energy reduction.	+20%	+2%		

[a] Linear increase over Baseline, reaching the % change by 2030.
[b] Linear increase over Baseline, reaching the % change by 2030. The different rates are correlatives to the investment ones.

MARCO33a and MARCO40a. Based on an off-model calculation (see Data Statement), this limit was set increasingly higher according to the respective energy reduction scenario, assuming that this reduction in final energy could explain exergy efficiency gains to some extent. This is consistent with the stagnation of this variable since the early 2000's and is also coherent with the existence of thermodynamic limits discussed in section 4. This applies to MARCO27a, MARCO33a and MARCO40a (energy scenarios).

Second, exogenous socioeconomic assumptions that apply to MARCO27b, MARCO33b and MARCO40b (socioeconomic scenarios) are collated in Table 2:

Given the uncertainty associated to the EXEFF_FU evolution and its feasible thresholds, the socioeconomic-extended scenarios (MARCO27b, MARCO33b and MARCO40b) remove any thermodynamic efficiency constraint. The expected consequences of applying these different scenarios assumptions can be tracked in the MARCO-UK's causality and feedback loops overview shown in Figure A1. According to the description given there, the restriction of thermodynamic efficiency, besides being one of the main novelties of MARCO-UK, implies a relevant influence on the results. As a direct consequence, on the one hand, the virtuous cycle (feedback 3) of capital investment-energy efficiency-GDP growth is restrained. On the other hand, the negative feedback loop (6) from thermodynamic efficiency to employment demand is reversed, turning labour more necessary when efficiency cannot rise any more. However, a trade-off arises as the simultaneously-reduced GDP growth also reduces labour demand. This is further discussed in Sections 3 and 4. We suppose that energy reduction scenarios with the thermodynamic constraint would act as a minimum and the socioeconomic-extended ones as the maximum expected outcomes. As a result, the area in between would represent the likely outcomes provided that thermodynamic efficiency could range from the minimum (22%) to the maximum (35%) that occurs when the simulation runs free.

3. Results

Given the abovementioned methodological approaches, as well as the scenarios assumptions, the simulations produce different outcomes. As mentioned before, the purpose is focusing on the influence of different methodological approaches and scenarios hypotheses on the outcomes. To facilitate this and comparability, all the scenario results have been homogenised. Hence, the main outcomes are showcased as the difference with their own model's Baseline. This means that the E3ME and MARCO-UK's baselines are set as a common 100 value for 2018–2030, and each model scenario is shown as the volume variation respect their respective Baseline. Nevertheless, Appendix B summarises all scenarios results independently in levels and as percentage change (2018–2030) in Table B.1 and Table B.2. It is worth noting the relevance of reading these results in the light of the modelling assumptions highlighted in sections 2.3.2 and 2.3.3.

Table 2
Extended description of the socioeconomic scenarios.

Macroeconomic Variable	Extended description of the scenarios assumptions
Capital Investment (I)	Increased to finance the energy savings (e.g. building retrofit, grid balancing, etc.): +10% in EUCO27 (2.65% yearly average); +15% in EUCO33 (2.98% yearly average); +20% in EUCO40 (3.29% yearly average). All against 2030 Baseline. Here it is covered all gross capital formation, regardless of its precedence (public or private).
Quality-adjusted labour (hl_index)	Assumed an increase of 300,000 highly skilled workers now employed as estimated in Nieto et al. (2019). This represents around 1% of total UK workforce in MARCO27b. So it is assumed that these were unskilled-to-skilled workers. This increases the labour skills index (HL) value by 0% (year 0) rising to +1% by 2030. MARCO33b and MARCO40b increases are correlative to their respective capital investment efforts.
Government expenditures (G)	Set as the last decade's 19% of GDP (not included government investment) instead of projections based on Baseline. This turns G endogenous, reinforcing all possible expansive or containment cycles.
Energy prices	Set as the MARCO_Base scenario, in order to avoid an undesired energy prices escalation.

3.1. GDP and capital investment

Regarding GDP evolution (see Fig. 5), it is observed that the E3ME results show small increases as energy use is reduced. A different landscape is offered by the MARCO27a/33a/40a simulations (shown by the solid lines in Fig. 5), where we find the higher the reduction in energy consumption, the lower the GDP outcome. However, the MARCO27b/33b/40b simulations show that once the thermodynamic efficiency constraint in the model is removed, and the socioeconomic assumptions are included, GDP becomes higher as energy consumption is reduced (the dotted lines in Fig. 5). By 2030, whereas the E3ME scenarios are +0.3%–1.0% above their Baseline, the MARCO27a/33a/40a scenarios are −4% to −7% below baseline, whilst the MARCO27b/33b/40b scenarios are +2.8% to +4.5% compared to their Baseline. Hence, the MARCO-UK macroeconomic outcomes are more sensitive to energy use.

Regarding capital investment (see Fig. 6), the E3ME scenarios showcase a similar slightly below Baseline tendency for EUCO33 and EUCO40 scenarios. Conversely, EUCO27 appears as relatively stable at the Baseline levels, although going slightly up at the end of the simulation period. The efficiency-constrained MARCO27a/33a/40a scenarios set by the MARCO-UK model show a reduction in capital investment due to the contraction of the economy described previously in the GDP results. Nevertheless, differences among MARCO27a/33a/40a scenarios are only significant after 2027, when the thermodynamic efficiency limits start tightening. Conversely, without efficiency constraints, the socioeconomic MARCO 27b/33b/40b scenarios permit capital investment increases. As the two model's results were homogenised as described at the beginning of Section 3 in order to facilitate comparability, Fig. 6 does not exactly match the capital investment figures in Table 1 for MARCO27b/33b/40b (+10%/+15%/+20%).

3.2. Employment and socio-economy

According to Fig. 7, total employment would increase in all scenarios for both models. The E3ME scenarios show a steady increase, that is higher as the final energy use reduction is more intense (because none of the scenarios get close to full employment). The additional employment compared to the no-policies scenario (Baseline) oscillates between 67,000 and 182,000 new jobs. The MARCO-UK scenarios show a more variable path, as there is a first increase at the beginning, followed by a relative stability that goes back to increasing at the end of the simulation. The differences between the thermodynamic efficiency constrained MARCO27a/33a/40a scenarios are wider than the socioeconomic MARCO27b/33b/40b scenarios. The MARCO27a/33a/40a scenarios imply, as in the E3ME scenarios, that the initial gains due to the restricted efficiency-induced increase in labour demand are slowed down later in the simulation, as the reduced GDP decreases employment creation (see Figure A 1). Despite the overall increase of employment in the MARCO27b/33b/40b scenarios, the model feedbacks operate to moderate them, prompting a tighter banding of results, with two saturation stages, one at the middle of the period and another one at the end. The forces that contribute to balancing –containing- the employment creation are the increase in capital services –driven by the increase in capital investment- and the negative trade balance –driven by the increased wages and total consumption-feedback loops (see Appendix A - Figure A1). The effects of the model scenarios on consumer prices are shown in Appendix C (Figure C1).

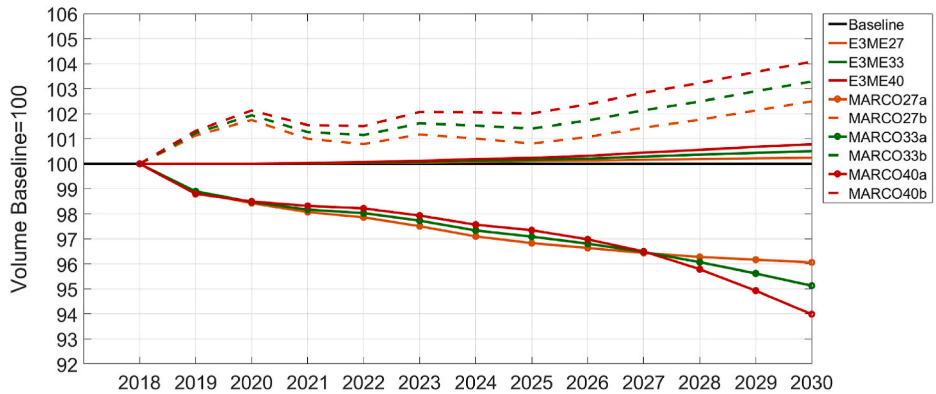


Fig. 5. GDP estimates under E3ME and MARCO-UK scenarios versus respective baselines.

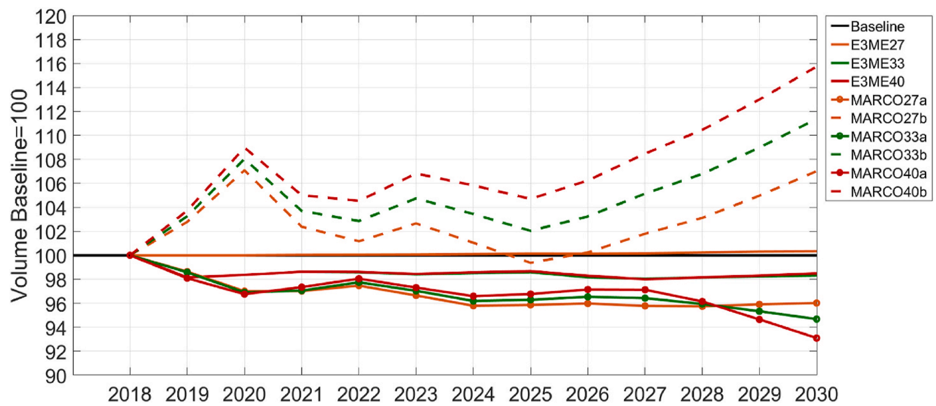


Fig. 6. Capital investment estimates under E3ME and MARCO-UK scenarios.

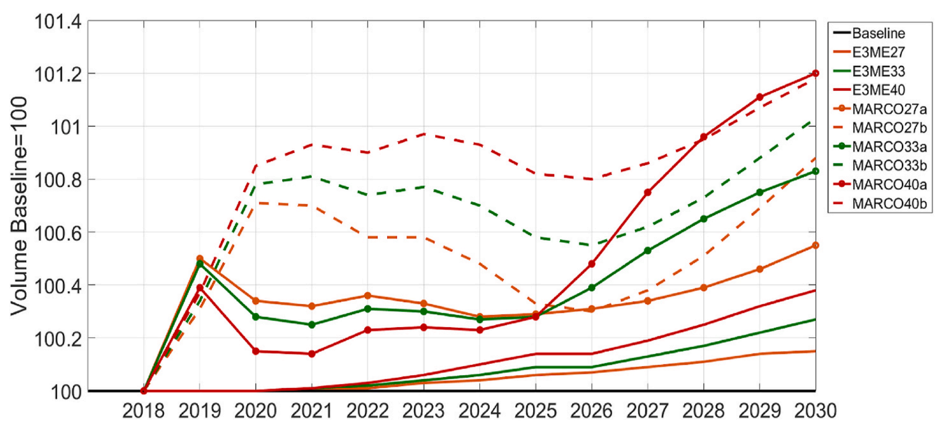


Fig. 7. Total employment estimates under E3ME and MARCO-UK scenarios.

3.3. *Energy use and CO_2 emissions*

Regarding total final energy use (see Fig. 8), all scenarios necessarily show net reductions compared to Baseline. MARCO-UK reduction of energy use is an exogenous initial hypothesis –the same for the energy and socioeconomic scenarios-that holds across the simulation period. Conversely, the energy use remains as an endogenous variable in the E3ME model, subject to the evolution of and the intertwines with the rest of the model. As a result, the energy reduction turns lower as the GDP growth is higher, suggesting a rebound effect that is discuss in section 4. This can be noticed in Table B2 in Appendix B, showing the percentage 2018–2030 variation in absolute terms. The gap between the E3ME energy reduction (−9.2%, −15.7% and −22.3%) grows wider compared to the exogenous MARCO-UK energy reduction (−11.7%, −19.9% and −28.5%) as the GDP prospects increase in the E3ME scenarios. Moreover, it is also worth mentioning for a correct interpretation of Fig. 8, that the MARCO-UK energy reduction compared to Baseline is steeper not only due to the energy reduction in absolute terms described,

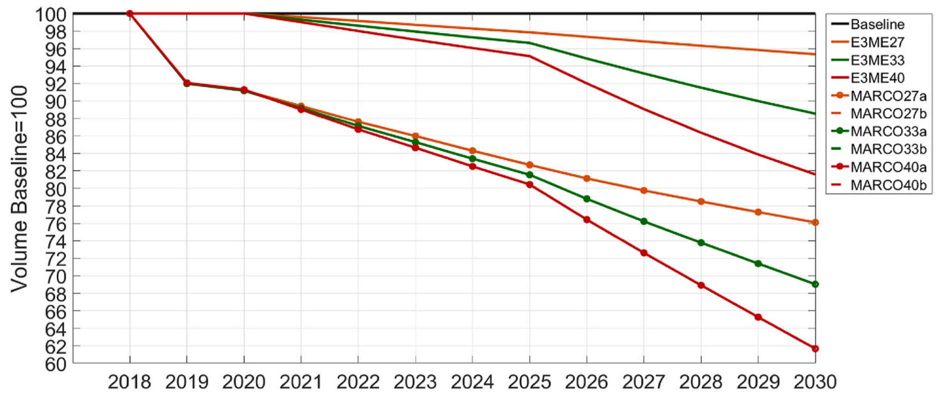


Fig. 8. Total final energy use estimates under E3ME and MARCO-UK scenarios.

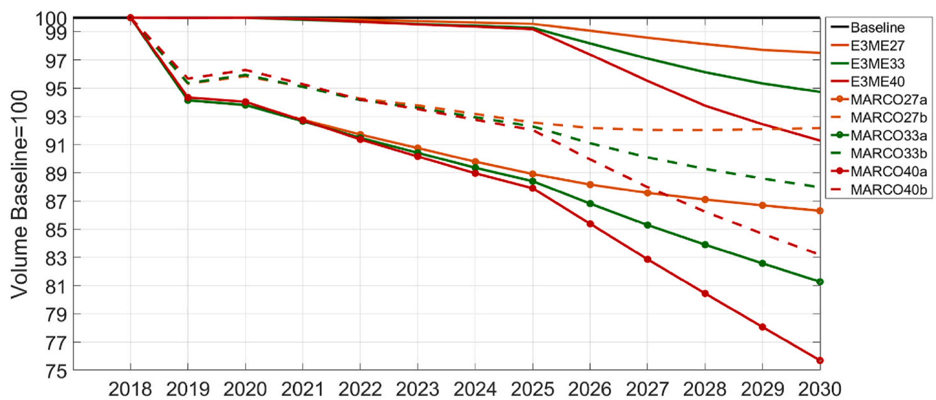


Fig. 9. CO_2 emissions estimates under E3ME and MARCO-UK scenarios.

but also because MARCO-UK's Baseline predicts higher energy use than the E3ME's. Whereas MARCO-UK forecasts a 7.3% increase of energy use by 2030 if no policies are applied, E3ME estimates a −4.3% reduction for the same period (see Table B2 in Appendix B), which is closer to the European Union's projections (European Commission, 2016).

Finally, the effects on CO_2 emissions is shown in Fig. 9. Although all scenarios show a decrease in the total emissions, the effects are more intense in MARCO-UK than in E3ME, as lower energy use has lower associated CO_2 emissions. The E3ME scenarios decrease compared to Baseline initially at a very slow rate, followed by a sharp decline after 2025. On the other hand, the MARCO-UK scenarios show a steady reduction in emissions compared to Baseline in all the energy scenarios across the whole time period. We find the socioeconomic (MARCO 27b/33b/40b) scenarios outcomes are closer to those of the E3ME model, as with higher GDP the non-energy CO_2 emissions grow. Whilst all emissions reductions are related to the magnitudes of energy use decrease showed in Fig. 8, the interruption of a steeper decrease could be linked (both in E3ME and the socioeconomic MARCO-UK scenarios) with a rebound effect driven by the boost of GDP (see Fig. 5).

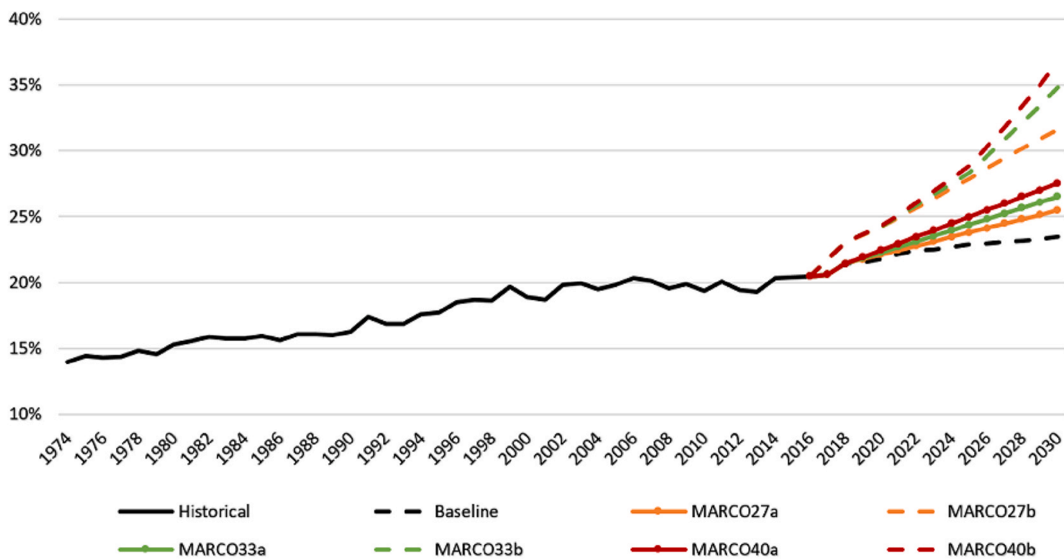
3.4. *Thermodynamic (energy) efficiency*

The MARCO-UK model gives us the opportunity to review past UK energy efficiency with the scenario assumptions in the analysis. Fig. 10 shows the evolution of thermodynamic efficiency by scenarios in MARCO-UK and its factor variation between selected historical intervals.

Factor variation represents the ratio of the value of thermodynamic efficiency between the upper bound and the lower bound of the time interval (2016–2030 in the case of scenarios).

Firstly, it can be noticed how the UK's thermodynamic efficiency growth has constantly been declining from a 1.24 growth factor (1974–1991) to 1.04 (1999–2016), while the overall period's (1974–2016) factor variation was 1.47. Secondly, that all MARCO-UK scenarios (except MARCO27a) would entail a thermodynamic efficiency growth higher than the achieved during the initial high-growth phase (1974–1991). Moreover, all the socioeconomic (MARCO27b/33b/40b) scenarios more than outpace the thermodynamic efficiency growth of 1974–2016 (42 years) in the following 14 years. These large thermodynamic efficiency gains may be indicating the biophysical unfeasibility of simultaneously supporting such final energy use reductions (see section 3.3) and GDP growth rates (see section 3.1).

The allowance of unrestrained thermodynamic efficiency gains in the socioeconomic scenarios is problematic at a physical level, when we take into account the fact that there exists thermodynamic (biophysical) constraints to unlimited efficiency that cannot be trespassed (Georgescu-Roegen, 1971; Groscurth et al., 1989; Ayres, 2007). These limits are more or less known at the device level (Paoli and Cullen, 2020), but remain more uncertain at the territorial or country level. However, this uncertainty would not justify disregarding this physical reality. In fact, the UK's observed thermodynamic efficiency trajectory seen in Fig. 10



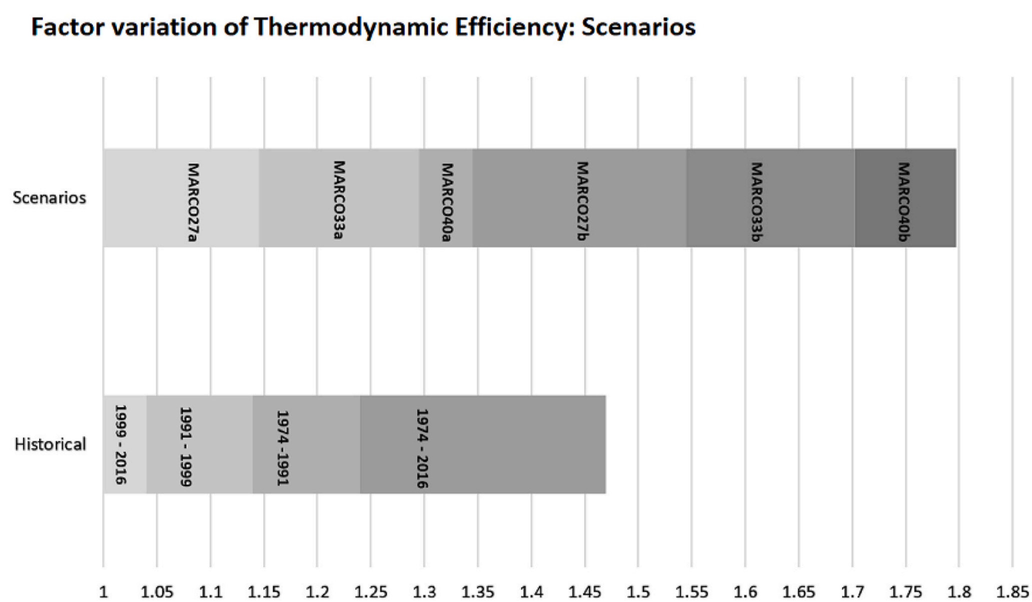


Fig. 10. UK Thermodynamic (energy) efficiency. Time series by scenarios (top) and factor variation by scenarios and selected historical intervals (bottom).

since the 1970s and its relative stagnation during the last decades would suggest that the country is running closer to this limit.

4. Discussion

From the results obtained, there are several key findings to discuss in some detail. Firstly, regarding GDP, the E3ME model results imply that energy use reductions lead to higher GDP, as energy (cost) savings encourage economic growth. These results are consistent with the results from the EU Impact Assessment. The MARCO-UK results reveal a more nuanced story on GDP growth. Due to the importance of energy efficiency within the MARCO-UK model, the inclusion of thermodynamic efficiency limits translates to constrained GDP growth in the socioeconomic (MARCO27b/33b/40b) scenarios. However, if the thermodynamic efficiency constraints can be overcome, as allowed in the other set of (MARCO27b/33b/40b) scenarios, then significant economic growth is permitted, due to the model assigning the standout Keynesian role of capital (Sakai et al., 2018), as shown in Fig. 6.

Second, we find higher total employment observed in Fig. 7, in all modelled scenarios for both models. Of particular note is that we find the largest increases in employment occurring in the scenarios which have the largest energy savings, i.e. EUCO40. For E3ME, the EUCO40 scenario raises employment by 0.4% above baseline, representing an extra 120,000 annual jobs. For MARCO-UK, the employment gains in both EUCO40 scenarios were higher (1.2% above baseline), equivalent to 360,000 additional jobs in 2030. However, the similarity of the MARCO-

UK results may be hiding differences between the type and quality of additional jobs, as the initial increase is induced by the restricted efficiency. A core component of the MARCO model - see Appendix A (Figure A1) - is the delivery of energy services via the joint contribution of capital and labour (Dincer, 2000; Fukuda, 2003; Chen and Chen, 2009). Therefore, in the MARCO27a/33a/40a scenarios – where thermodynamic efficiency and capital are constrained, more jobs (of lower quality) are input to boost energy services and GDP. Conversely in the unconstrained socioeconomic MARCO27b/33b/40b scenarios, the positive effects on consumption, investment and the reinforcing positive feedback loop of government expenditure - i.e. the role of energy services on stimulating aggregate demand - lead to gains in higher quality jobs within a growing economy.

A third finding to discuss is the impact of energy efficiency and rebound. The MARCO-UK model's unconstrained socioeconomic (MARCO27b/33b/40b) scenarios reveal how gains in energy efficiency lead to higher gains in economic growth. A key caveat is shown in Fig. 10, which reveals the very large required increases in thermodynamic efficiency required in those scenarios. Given thermodynamic efficiency has remained stagnated in the UK during the last two decades, from 19.7% in 1999 to 20.5% in 2016, serious questions arise as to whether these large thermodynamic efficiency gains are in fact possible to reach, due either to biophysical limits or the practical difficulties to deliver them in that short period of time. Even if such limitations are overcome and the final energy reduction triggers a macroeconomic boost, energy rebound effects could emerge. The E3ME results in Fig. 8 and the Summary detailed tables (Table B2-Appendix B) show the impact of an endogenously-applied energy target, whereby rebound effects cause the additional use of energy, reducing the scale of energy reductions versus those originally intended.

Our study provides useful discussion points regarding policy. Given that policy-induced energy use reductions typically rely upon energy efficiency gains, considering economy-wide thermodynamic constraints entails important policy considerations. Firstly, our findings show that once considered these limits, efficiency-oriented capital investment loses its effectiveness, reducing its capacity to boost economic growth (see feedbacks 2 and 3 in Figure A1). Moreover, the causal links leading to rebound effect would be broken, potentially harming the economy's capability to deliver further efficiency-oriented capital investment. When these limits are disregarded, our joint modelling simulation shows that setting the UK energy target to be most ambitious (at EUCO40 level) would give the most significant rises to GDP and employment, twinned with the largest reductions in energy and associated CO_2 emissions. However as noted earlier, raising thermodynamic (energy) efficiency by the required scale in such short time may not be practical, in which case GDP would be constrained to meet the energy target. This reaffirms the potential conflict between the achievement of socioeconomic and climate goals simultaneously (D'Alessandro et al., 2010; Kallis et al., 2012; Nieto et al., 2020a,b). Hence, considering economy-wide thermodynamic efficiency limits would advise moving energy policy beyond supply-side energy efficiency solutions.

The crucial issue is therefore how to deliver gains to energy efficiency, whilst limiting the potential for energy rebound. Given that the supply-side efficiency gains are close to reaching their limits or, at least, reducing their capacity to grow further, demand-side solutions to efficiency are advisable, especially in the context of reducing final energy demand. In addition, the current stagnation of overall UK energy efficiency (seen in Fig. 10) suggests that the nature of the efficiency policies might need to change to deliver efficiency improvements. In other words, the policies effectiveness would benefit from applying a macro view that seeks the satisfaction of the everyday needs with less overall energy use instead of by using a growing number of devices, trusting in their capacity to be more efficient.

Hence, within an avoid-shift-improve (ASI) framework, demand-side management policies should be aimed both at energy and greenhouse gases emissions (as reducing the latter is the ultimate objective). Policy actions within the ASI framework are targeted at urban planning, transport shift to collective, public and non-emissions modes, building retrofit, behavioural change, meat-reduced diets, etc. (Creutzig et al., 2016, 2018, 2018; Grubler et al., 2018; Owen et al., 2018; Nieto et al., 2020). To give concrete options, an 'avoid' policy can be an aggressive 2020–2030 building retrofit programme in the UK, where for example all homes are retrofitted to Band B energy performance. A recent MARCO-UK study determined that an improvement to 29% overall efficiency by 2030 could result from such a programme, whist cutting energy use and boosting employment (Figure 14, Nieto et al., 2020a,b). Another demand-sided option would be to focus on 'shifting' UK's economic activity through industrial policy to low energy consumption sectors.

In addition, if the macroeconomic outcomes are to be substantially improved, it would be advisable to accompany the energy targets with demand-side economic policies, for example linking to the renewable infrastructures needed to be deployed, implying capital investment, government expenditures, but also improving the quality of the jobs created and monitoring energy prices. Otherwise, the reduction of final energy use could only have small macroeconomic effects.

Last, rebound effects should also be explicitly considered within energy and climate policies, which stands in marked contrast to their current ignorance in policy inclusion. As a first step, inclusion of rebound effects (as are considered – in different fashions - within E3ME and MARCO-UK models) is sensible. Second, targeting the right combination of demand-sided energy reduction policies – focusing on demand-sided reductions rather than device efficiency - can also help to reduce undesired energy rebound effects. Such policies can be twinned with carbon/energy taxes to limit rebound effects. Third, demand-sided policies can be over-set above the intended effect, in order to compensate for unforeseen or unavoidable rebound effects.

5. Conclusions and policy implications

The energy transition in the UK responds to the objective requirements that tackling climate change involve. Moreover, an energy demand reduction proves necessary to be combined with a shift to renewables in the energy mix. Therefore, as we move – in a post-Brexit space - from the European Union to the UK government who determines the ambition, the UK's final energy use must be reduced in the following years to cope with the mandated carbon budgets and 2050 Net Zero targets. Provided the existence of an energy-economy nexus, the socio-macroeconomic consequences of the UK energy targets are evaluated in this paper using two macroeconometric E3 models: E3ME (Cambridge Econometrics, 2019) and MARCO-UK (Sakai et al., 2018). Six scenarios with different assumptions have been modelled, though all of them share the same energy reduction targets set by the European Union, namely: EUCO27, EUCO33 and EUCO40.

The outcomes show that the energy reduction targets could improve both the UK's GDP growth and employment creation prospects, with EUCO40 – the most aggressive energy reduction target – achieving the largest benefits. To do so, we need to create the efficiency headroom for that to happen, by a rapid increase in thermodynamic efficiency. A faster switch from fossil fuels to renewable energy supply will be part of how that can happen. But alongside this, we suggest a switch of focus from supply-side to demand-side policies, or at the very least a rebalancing of policy to merit their equal inclusion.

For example, this would entail a much stronger regulatory action to improve the thermal efficiency of buildings – the current UK retrofit programme would need significant increase to its ambition. Other demand-sided measures within an avoid-shift-improve framework include 1. Foreclosing future airport and road expansion; 2. Rapid electrification of key sectors including domestic heating, transport and industry; 3. Achieving significant improvements to industrial energy efficiency; 4. Shifting travel from cars to public transport and active travel, and 5. Moving away from meat-based diets. However, the potential offshoring of GHG emissions due to the increased GDP growth must not be disregarded, even if these demand-sided policies are implemented.

A key challenge will be dealing with efficiency and rebound. To realise the socioeconomic gains and deliver energy reductions, a significant thermodynamic efficiency uplift will be required; conversely, if efficiency is about to reach its thermodynamic limits, reduced final energy use might eventually lead to a low GDP growth regime. A restructure of the economy to less energy intensive sectors could enable the economy to cope with these limits. On the other hand, if the UK's economy is able to overcome the thermodynamic hurdles, the additional mitigation strategies may be required to limit the effects of energy rebound effects that could hamper meeting the energy targets because of the increased aggregate demand of goods and services driven by the employment and GDP rises.

In order to achieve a stable socio-macroeconomic energy transition path, it could be advisable to focus on the demand-side management policies first while setting the energy targets by stages, e.g. dividing the period in three equal parts and targeting to EUCO27 in the first one, EUCO33 in the second one and finally reaching EUCO40 in the last one. The coronavirus pandemic has led to many to discuss how to 'build back better'. It is possible for example that this opportunity for reset could be harnessed, and an aggressive target of EUCO40 could be pursued as part of a Green New Deal set of policies, rather than just to reinstate the existing fossil fuel based industries.

Therefore, policy makers should pay attention to all these issues when deciding the post-Brexit UK energy targets. The economic downturn unleashed after the onset of the COVID pandemic suggest the necessity to pursue a rapid energy mix shift to renewables along with bold demand-side strategies by policy-makers, rather than focusing on rebuilding existing energy-intensive infrastructure. Many of these measures can address aspects of energy poverty and wellbeing, helping with the goal of delivering a 'just' energy transition.

Data statement

Links to off-model calculation are placed in a University of Leeds data repository, which for this study can be found at https://doi.org/10.5518/1043, in accordance with EPSRC funding requirements.

CRediT authorship contribution statement

Jaime Nieto: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Hector Pollitt:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Paul E. Brockway:** Conceptualization, Funding acquisition, Methodology, Project administration, Validation, Writing – review & editing. **Lucy Clements:** Data curation, Formal analysis. **John Barrett:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. MARCO-UK model – extended description

The extended description below is intended to present a short summary of the three key GDP identities and the final-to-useful energy identity, together with the energy-macroeconomic feedbacks, which are of particular importance in this paper. For a full description of the model refer to Sakai et al. (2018) – Supplementary Information, where details of each equation and variable are described, including sources for all the annual data used in the model construction.

Three Gross Domestic Product (GDP) identities are given by the accounting definitions of GDP (Y). First, from the expenditure side, Y is equal to the sum of private (CT) and public (G) consumption, capital investment (I) and net exports (X-M) as in Eq. (1). With CT split in energy and non-energy expenditures. Whereas all the GDP components are estimated with behavioural equations, government expenditures (G) can be set either as an exogenous projection or as percentage of GDP.

$$Y_t = CT_t + I_t + G_t + X_t - M_t \qquad \text{Eq. 1}$$

Second, in order to match GDP identities, it is also estimated from the income side, as the total national income, i.e. compensation of employees or wages (W), profits received by firms (PROFIT) plus net taxes on production and products (NET_TAX), as given in Eq. (2):

$$Y_t = W_t + PROFIT_t + NET\_TAX_t \qquad \text{Eq. 2}$$

Third, GDP is also constructed by GVA-based Eqn 3:

$$Y_t = GVA_t + NET\_TAX_t \qquad \text{Eq. 3}$$

All three identities must hold true in each time period to be consistent. Other relevant variables considering the analysis carried out in this article are labour demand (L), consumer prices (CPI), useful exergy (UEX_TOT) and thermodynamic efficiency or final to useful exergy. (EXEFF_FU). As long as EXEFF_FU is endogenous, it is set as an identity Eqn 4:

$$EXEF\_FU_t = \frac{UEX\_TOT_t}{FEN\_TOT_t} \quad \text{Eq. 4}$$

The particular functional forms of these and the rest of variables, as well as the choice of explanatory variables are empirically validated and tested using econometric techniques. For validation and a more elaborated description of the equations, see Sakai et al. (2018) and its supplementary materials.

Furthermore, the comprehension of the energy-macroeconomic main feedback loops is crucial to disentangle the policy challenges of the energy transition. The MARCO-UK model identifies 5 relevant energy-macroeconomic feedbacks in the UK's economy (see Figure A1):

Positive (or reinforcing) feedbacks:

1. Capital Investment (+) → GDP (+) → Labour demand (+) → Total wages (+) → Consumption (+) → GDP (+)
2. Capital Investment (+) → Energy efficiency (+) → Energy services (+) & Lower cost of goods (−) → Increased final energy use (+) & Incentivise production (+) → Capital Investment (+).
3. Capital Investment (+) → Energy efficiency (+) → Non-energy consumption (+) → GDP (+)

   Negative (or balancing) feedbacks:
4. Capital Investment (+) → GDP (+) → Labour demand (+) → Total wages (+) → Consumption (+) → Trade balance (−) → GDP (−).
5. Capital Investment (+) →Capital services (+) → Labour demand (−) → Total wages (−) → Consumption (−) → Lower GDP (−)
6. Capital Investment (+) → Energy efficiency (+) → Energy services (+) → Labour demand (−) → Total wages (−) → Consumption → GDP (−)

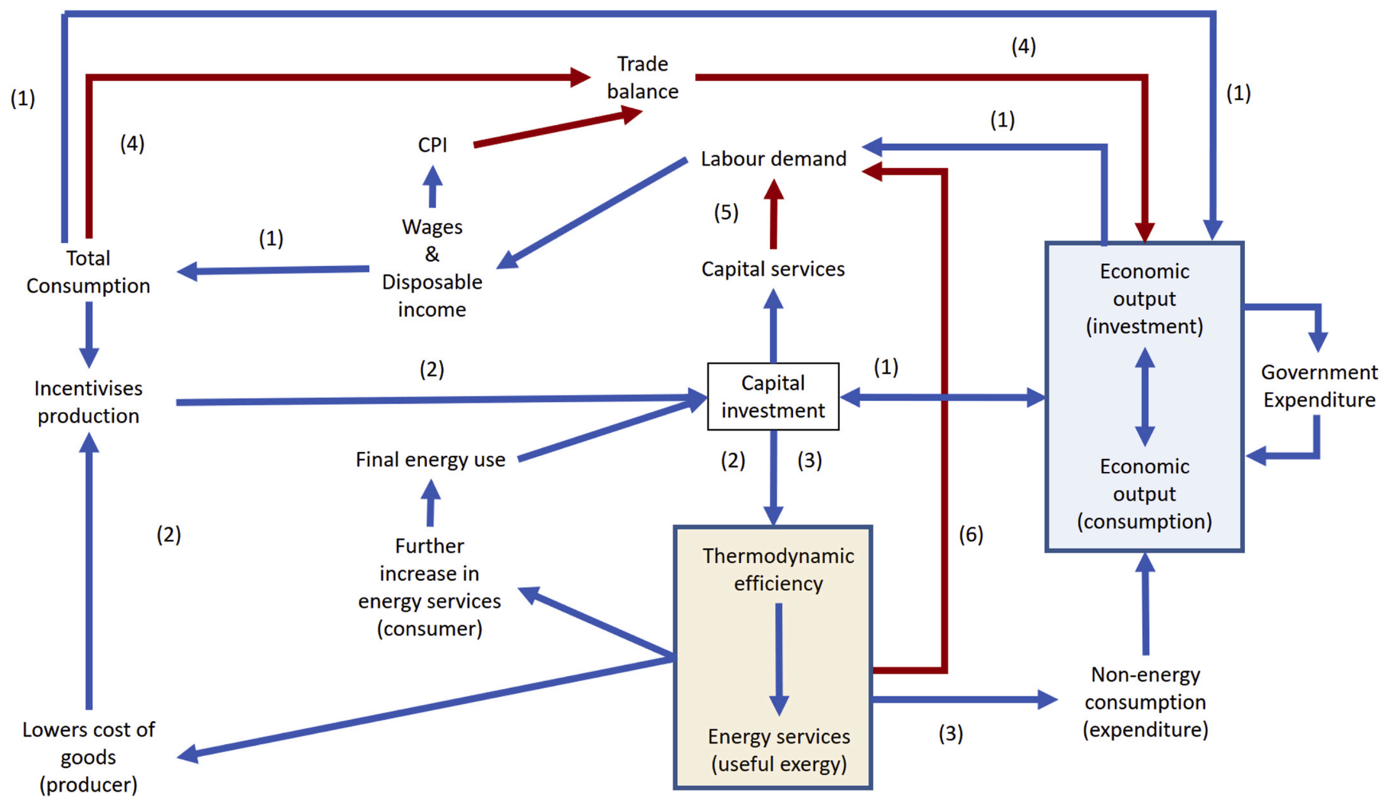

Fig. A1. MARCO-UK's main causality and feedback loops overview.

Key:

- Blue arrows represent positive relationship between variables, i.e the final variable increases (decreases) if the initial one increases (decreases) too.
- Red arrows represent negative relationships between variables, i.e. the final variable decreases (increases) if the initial one increases (decreases).
- Number in brackets above the arrows represent the different feedbacks (1–6) pathways.

Feedbacks 2 and 3 represent the rebound effect (Alcott, 2005; Ayres, 2007; Alcott et al., 2012; Duarte et al., 2013; Sakai et al., 2018) as the initial increase in energy efficiency eventually leads to an increase in demand that compensates in absolute terms for the initial relative gains in efficiency. However, feedback 2 has been implicitly disabled in this analysis by assuming that the economy-wide energy reduction planned holds exogenously throughout the simulation period. Moreover, whereas feedbacks 1 and 3 can stimulate the main macroeconomic outcomes either via energy efficiency or employment creation (feedback 1), feedbacks 4, 5 and 6 would operate in the opposite direction. Feedback 1 stimulates overall consumption, which results in an increment of imports (M) and the increase of CPI. This harms exportation (X) and all together results in a deterioration of the trade balance (X-M). In addition, an increase in capital investment would entail an expansion of the capital stock (feedback 5), turning labour less attractive to employers. So, employment would be reduced, producing the opposite effects as in feedback 1. Feedback 6 states the same but now applied to energy services. If energy services are increased per unit of output, then labour is relatively less demanded.

In practice, all these feedbacks operate simultaneously, as in the real economy. Therefore, the results would vary depending on the forces dominating in the analysis, the respective scenarios assumptions and the intensity of the stimulus applied.

Appendix B. Summary detailed tables

Table B.1
E3ME and MARCO-UK outcomes in levels by 2030 under different scenarios

	Units	E3ME-Baseline	E3ME27	E3ME33	E3ME40	MARCO-Baseline	MARCO 27	MARCO 27b	MARCO 33	MARCO 33b	MARCO 40	MARCO 40b
GDP	£ millions	2,886,156	2,893,206	2,900,739	2,908,568	3,463,326	3,326,842	3,549,899	3,294,709	3,577,248	3,255,083	3,604,620
CPI	index (2005 = 100)	1.75	1.75	1.74	1.73	1.85	1.82	1.83	1.84	1.84	1.87	1.84
Consumption	£ millions	1,700,318	1,705,002	1,709,080	1,713,210	2,194,891	2,110,899	2,196,180	2,108,701	2,202,902	2,105,143	2,210,451
Investment	£ millions	520,639	522,399	523,174	524,506	499,856	479,966	534,922	473,262	556,718	465,343	578,515
Exports	£ millions	815,851	816,013	815,969	815,809	1,314,404	1,197,430	1,329,962	1,174,158	1,330,429	1,145,418	1,330,919
Imports	£ millions	905,045	904,601	901,878	899,351	1,570,939	1,464,545	1,571,710	1,462,880	1,580,275	1,460,171	1,589,824
Employment	000s	32,826	32,876	32,913	32,952	34,613	34,803	34,917	34,900	34,969	35,028	35,022
Terrestrial CO2 emissions	000s tonnes	93,984	91,642	89,040	85,799	144,531	124,749	133,218	117,470	127,161	109,411	120,242
Total final energy demand	000s toe	125,915	120,063	111,509	102,741	146,335	111,391	111,391	101,025	101,025	90,263	90,263

Table B.2
E3ME and MARCO-UK outcomes as a % variation (2018–2030) under different scenarios

	Units	E3ME-Baseline	E3ME27	E3ME33	E3ME40	MARCO-Baseline	MARCO 27	MARCO 27b	MARCO 33	MARCO 33b	MARCO 40	MARCO 40b
GDP	£ millions	16.9%	17.2%	17.5%	17.8%	32.5%	30.5%	38.3%	29.2%	39.3%	27.7%	40.4%
CPI	index (2005 = 100)	32.4%	31.9%	31.4%	30.8%	34.0%	34.7%	36.4%	36.1%	36.7%	38.6%	37.2%
Consumption	£ millions	18.3%	18.6%	18.9%	19.2%	41.9%	39.8%	45.4%	39.7%	45.8%	39.4%	46.3%
Investment	£ millions	23.4%	23.8%	24.0%	24.3%	28.4%	23.8%	37.9%	22.0%	43.6%	20.0%	49.2%
Exports	£ millions	20.8%	20.8%	20.8%	20.8%	64.2%	58.9%	72.7%	55.9%	72.7%	52.3%	72.8%
Imports	£ millions	21.5%	21.5%	21.1%	20.8%	84.2%	81.7%	94.8%	81.5%	95.8%	81.0%	97.1%
Employment	000s	5.8%	5.9%	6.0%	6.2%	11.8%	12.4%	13.4%	12.8%	13.6%	13.2%	13.8%
Terrestrial CO2 emissions	000s tonnes	−19.2%	−21.2%	−23.5%	−26.2%	11.5%	1.8%	8.3%	−4.1%	3.4%	−10.9%	−2.5%
Total final energy demand	000s toe	−4.8%	−9.2%	−15.7%	−22.3%	7.3%	−11.7%	−11.7%	−19.9%	−19.9%	−28.5%	−28.5%

Appendix C. consumer prices

Considering prices, Figure C1 shows the trajectory under different scenarios of the consumer prices index (CPI). Whereas prices are higher as the energy is more reduced for the E3ME scenarios, the MARCO-UK energy scenarios show the opposite tendency. Nevertheless, this is reversed back to the E3ME rationale when the socioeconomic features are applied and the thermodynamic efficiency constrain is removed for the first simulation years. Then, the energy prices control in these scenarios have a wider effect as the energy reduction is larger and the socioeconomic scenarios show a similar profile as the energy ones. MARCO33b is almost reached by MARCO27b at the end, showing a similar trend of the EUCO27 to catch up with EUCO33 for both models. Due to the exogenous intervention in the MARCO-UK socioeconomic scenarios to maintain energy prices stable at the Baseline level, the overall prices (CPI) oscillate around the Baseline outcomes. Again, the MARCO-UK outcomes present a higher level of dynamism across the simulation period.

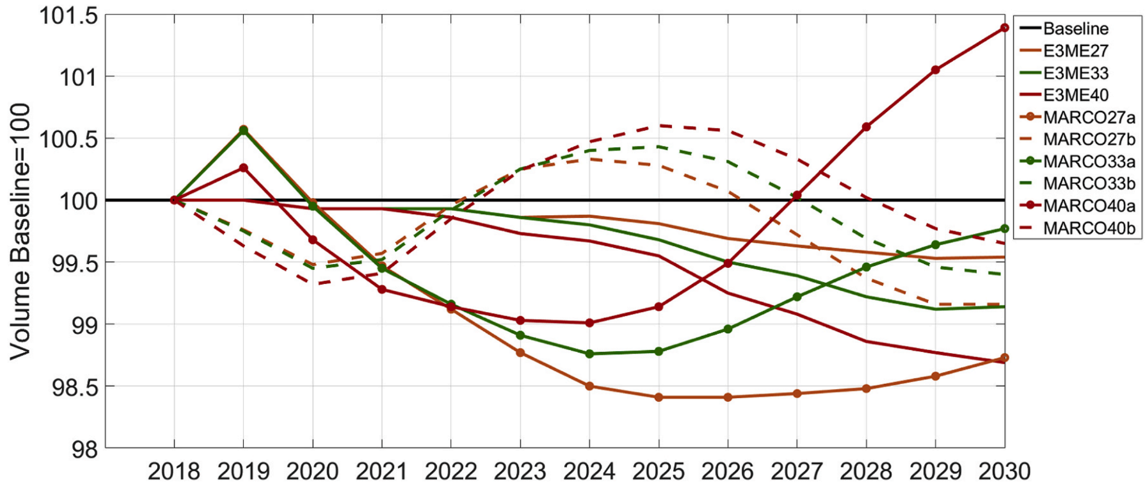

Fig. C1. Consumer Prices Index (CPI) estimates under E3ME and MARCO-UK scenarios.

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